California Community Colleges

Preparatory Pathways and STEM Calculus Completion: Implications of the AB 1705 Standards, Technical Appendices

February 2024

In partnership with

The RP Group

Research, Planning & Professional Development for California Community Colleges

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Introduction

This technical appendix accompanies the report, *Preparatory Pathways and STEM Calculus Completion: Implications of the AB 1705 Standards*. The appendices contain a full methods section and multivariate analyses that augment the descriptive analyses presented in the report.

Together, these analyses examined a cohort of more than 37,000 STEM majors who began in a transfer-level course in a calculus pathway at a California community college between 2012-2013 and 2019-2020 to determine – based on their high school math preparation and high school GPA – the implications of AB 1705 standards in practice. The law sets standards for students' placement and first math enrollment to ensure STEM students begin in transfer-level coursework that best positions them to complete calculus requirements for their programs.

Appendix A: Methods

Data Source

Data were obtained from the California Partnership for Achieving Student Success (CalPASS) data system with technical assistance from Education Results Partnership (ERP) who manage the system. The CalPASS data system contains anonymous student-level data from participating K-12 and postsecondary institutions including the Chancellor's Office Management Information System (COMIS) data sets and allows researchers to examine student progression through curricular sequences, such as when they transition from high school to community college.

The Outcome Variable Throughput

Consistent with prior AB 705 and AB 1705 validation studies, the analyses in this report used throughput as an outcome metric, specifically STEM Calculus 1 and STEM Calculus 2 throughput. Calculus throughput is a rate that counts successful calculus completions based on the count of students who start in a specified course in the calculus pathway (college algebra, trigonometry, precalculus, STEM Calculus 1). For example, if 200 students start in Precalculus, 60 progress to Calculus, and 50 pass Calculus, the Calculus 1 throughput is 25% (50 out of 200). Because throughput connects completion of calculus to math placement and initial course enrollment, it measures the efficacy of the placement system and associated curricular structures in supporting calculus completion. All STEM students whose first math enrollment is in STEM Calculus 1 or a preparatory course prior to STEM Calculus 1 are included in the calculation of throughput. Throughput is lowered by students not passing a course in the calculus pathway or not persisting after a course success.

Throughput in this study includes the successful completion of STEM Calculus 1, within two years, or Calculus 2, within three years from the student's initial math enrollment. For example, if the first math enrollment was in Fall 2019, students are tracked through Summer 2021 for STEM Calculus 1 completion and Summer 2022 for Calculus 2 completion. AB 1705 specifies that placement must maximize gateway math course completion within one-year of first math course enrollment (California Educational Code 78213 section (c)(1)). However, these analyses used a 2-year timeframe to accommodate the longer calculus pathways at many colleges. This approach allows an examination of the full potential of a longer path to improve calculus completion.

Students were tracked for two years from their first math enrollment anywhere in the California Community College system. In other words, a student could begin the sequence at one college and complete it at another college resulting in more inclusive (i.e., higher) throughput rates than would be seen for within local college analyses.

Cohort

The cohort is California Community College (CCC) STEM majors whose first college math enrollment was in a transfer-level calculus pathway course (college algebra, trigonometry, precalculus, or STEM Calculus 1) at any point in the academic years between 2012-2013 and 2019-2020, excluding students who started a community college calculus pathway course while in high school or during a summer term. The study also does not include students who began in developmental education because they were the subject of previous validation studies and are not the focus of the section of AB 1705 that sets standards for placement into the first STEM Calculus course (Ed. Code 78213, section (f)). The cohort is further limited to students with an educational goal of degree, transfer and undecided (SB14 = A, B, C, M).

Community College Major

Majors were assigned using SS02 or SM02 (https://webdata.cccco.edu/ded/ded.htm). Six-digit TOP codes were used to assign students to a major. The TOP codes used to identify STEM Majors (based on Transfer Model Curriculum (TMC)) are listed in Table 1.

Table 1. TOP Codes of STEM Majors Requiring Calculus

STEM Major (TOP Description)	TOP Code
Chemistry	1905.00
Computer Science	0706.00
Computer Science	0707.00
Computer Science	0707.10
Engineering	0901.00
Geology	1914.00
Math	1701.00
Physics	1902.00
Biology (Only requires 1 STEM Calculus Course)	0401.00
Biology (Only requires 1 STEM Calculus Course)	4902.00

Community College Math Typology

Community colleges also have an extensive set of course codes (CB00) as part of the Chancellor's Office Management Information System (COMIS). The MMAP team built and maintains a math typology based on COMIS course codes which includes information from the Course Identification Numbering System (C-ID) to aid in the identification of equivalent courses across colleges. Information from college catalogs was also used to determine features of the local preparatory sequences, such as the number of courses within the sequence and how prerequisites were structured. All math ranks included in the analysis are presented below in Table 2. Only students who started in a course on the calculus pathway (i.e., Transfer Math Rank 4, 5, 6, or 8.1) are included in the sample.

Table 2. CCC Math Typology

Transfer Math Rank	Description
0	No Rank
1	Statistics
2	Liberal Arts Math
3	Finite Math
4	**College Algebra**
5	**Trigonometry**
6	**Precalculus**
7	Discrete Math
8.1	**STEM Calculus 1**
8.2	**STEM Calculus 2**
8.3	STEM Calculus 3
9	Differential Equations
10	Linear Algebra

STEM Calculus 1 Course Definition

STEM Calculus 1 is the first calculus course required for STEM majors and excludes Business Calculus and other forms of applied calculus. All colleges have a STEM Calculus 1 course equivalent to C-ID Math 210 Single Variable Calculus 1 Early Transcendentals, Math 211 Single Variable Calculus 1 Late Transcendentals, or the first half of a Math 900S Single Variable Calculus Sequence. (For quarter schools, C-ID 210 may be a two-course sequence.) For colleges without a certified C-ID Math 210, 211 or 900S course on c-id.net (college COMIS codes of 334, 522, 742, 745, 851, 951), the MMAP math typology was used to identify their STEM Calculus 1 courses. STEM Calculus 2 is a course certified by the C-ID as equivalent to Math 220 Single Variable Calculus 2 Early Transcendentals, Math 221 Single Variable Calculus 1 Late Transcendentals, or the second half of a Math 900S Single Variable Calculus Sequence, or a course identified in the Math Typology as STEM Calculus 2.

High School Performance Data

AB 1705 requires the use of high school transcript data as the primary tool in math placement. When high school transcript data is difficult to obtain or not available, the law requires colleges to use the student's self-reported high school information.

For this study, there were two sources of high school grade point average (HSGPA): self-reported CCCApply data and HS transcript information provided by EdResults Partnership's CalPASS Plus. If no CCC Apply data were available, HS transcript data were used. Students with either 11th or 12th grade data were included in the cohort. If a student has 12th grade data available, their 12th grade cumulative GPA is used. If a student only has up to 11th grade data, their 11th grade cumulative GPA is used.

Multiple quality checks were performed to determine if restricting the analysis to students with more years of available high school data changed the trends observed. More exclusionary criteria produced the same trends, so the decision was made to use the more inclusive criteria of 11th or 12th grade transcript data which allowed for a greater number of high school records. Multiple quality checks were also conducted to determine the quality and availability of high school transcript information.

These checks included but were not limited to comparing course codes to course titles, reviewing consistency of volume of records by year and school, and examining GPA distributions.

Categories of Math Courses in High School

High school math courses were categorized according to a K-12 typology that was originally created by the CalPASS and has been maintained by the MMAP team as systems and curricula evolved. The CCCApply application uses the categories from this typology.

California's adoption of Common Core standards led to some districts implementing "integrated" math sequences. For the purposes of this analysis, traditional and integrated sequences are combined. Tables 1 and 2 below show the mapping of codes to the highest high school course completed with a C or better.

Table 3. K-12 Math Typology from CCCApply Data (AP Mathematics Passed Course ID)

AP Mathematics Passed Course ID	Description	Highest HS Course (Assigned)
0	Unknown	NA
1	Prealgebra or lower	Geometry or lower
2	Algebra 1	Geometry or lower
3	Integrated Math 1	Geometry or lower
4	Integrated Math 2	Geometry or lower
5	Geometry	Geometry or lower
6	Algebra 2	Algebra 2
7	Integrated Math 3	Algebra 2
8	Statistics	Statistics
9	Integrated Math 4	Statistics
10	Trigonometry	Precalculus/Trig
11	Precalculus	Precalculus/Trig
12	Calculus or Higher	Calculus
13	Math Analysis	NA

Table 4. K-12 Math Typology from HS Transcript Data (MaxCourseContentRank_Math)

MaxCourseContentRank_Math	Description	Highest HS Course (Assigned)
1	Arithmetic	Geometry or lower
2	Prealgebra	Geometry or lower
3	Algebra 1	Geometry or lower
4	Geometry	Geometry or lower
5	Algebra 2	Algebra 2
6	Statistics	Statistics
7	Precalculus	Precalculus/Trig
8	Calculus 1	Calculus
9	Calculus 2	Calculus

Differences Between This Study's Cohort and Throughput Dashboard

There are differences in the sampling criteria between this study and the Transfer-Level English and Math Completion Dashboard which impact the throughput calculations. Because this study disaggregated students by high school performance metrics, it excluded students who are missing CCCApply data or 11th or 12th grade transcript data, but the dashboard does not use these filters. This study also excluded dual enrollment students by removing those who started a community college calculus pathway course while in high school or during a summer term, but dually enrolled students are included in the dashboard. In light of AB 1705 STEM Calculus placement standards, this study examined only students who started in a transfer-level math course in the STEM Calculus pathway. The dashboard, on the other hand, includes those who started below transfer level and assigns their initial course level based on their first transfer-level math course attempt in any pathway. This study's focus is STEM Calculus completion, so it excludes applied calculus courses such as Business Calculus or Calculus for the Social and Life Sciences; however, the dashboard includes all forms of calculus.

Appendix B: Multivariate Analyses

Multivariate Logistic Regression

To augment the descriptive analyses presented in the report, a series of multivariate analyses were conducted. The primary analysis used logistic regression to predict throughput in STEM Calculus 1 within two years, followed by a confirmatory decision tree analysis to mitigate method bias. The purpose of multivariate analyses is multifold. By including several predictor variables, one can assess the contribution of each variable to throughput while holding the influence of other variables constant. In addition, more nuanced relationships can be examined such as the interaction effects among different variables, which may be undetected in univariate analyses. The output of multivariate analyses also provides measures of overall model strength to indicate how much of the variation on throughput rates can be explained by the variables included in the model. For this analysis, predictor variables consisted of first transfer STEM math course, high school math level and GPA, the time between taking math in high school and college, student demographics, and the percentage of minoritized students at the high school of origin and at the college where the student first attempted STEM math. Table 5 below lists the variables used in the modeling.

Table 5. List of modeling variables

Variable	Description
Calculus 1 Two-Year Throughput (Outcome)	Completion of first semester STEM Calculus within two years of beginning transfer level STEM preparatory course or directly starting in STEM Calculus 1.
First CCC Math Course	Categorical variable of first community college transfer STEM math attempted.
Highest HS Math Course	Level of highest math class completed in high school with a C or better.
HS GPA	Cumulative unweighted high school grade point average.
Began Math Sequence Pre-AB705	Indicator variable for whether the cohort began before or after the wide scale implementation of AB705 (fall 2019).
Years between last HS math and first CCC math	Time in years between last high school math class completed with a C or better and first attempt in a college transfer level STEM math course.
Race/Ethnicity	Student ethnicity from CCCApply data using IPEDS categories.
Gender	Student gender from CCCApply data using traditional IPEDS categories (i.e., only female, male, and other). While this variable is referred to as “gender” throughout the report, the field is really measuring students’ reported sex.
Age	Age in years of the student as of their first math attempt at the community college.
EOPS	An indicator of whether or not the student was ever part of EOPS.
HS % Underrepresented Students	The percent of underrepresented students at the high school where the student completed their last math class with a C or better.
CCC % Underrepresented Students	The percent of underrepresented students at the community college where the student attempted their first math class.

Table 6 below shows the descriptive information for the sample. Due to need to link high school and college records, the students in the sample were both younger on average and have fewer years between high school and college math attempts than the typical community college student. Except for age, the demographics of the sample reflect the current state of STEM pathway participation rates, which may change over time with increased efforts to recruit and retain historically marginalized students.

Table 6. Sample Descriptives (percent of sample shown in parens)

Characteristic	N = 37,232
First CCC Math	
STEM Calculus I	11,648 (31%)
Pre-Calculus	10,667 (29%)
Trigonometry	9,489 (25%)
College Algebra	5,428 (15%)
Highest HS Course Completed	
Calculus	8,578 (24%)
Pre-Calculus/Trig	12,935 (36%)
Statistics	2,903 (8.1%)
Algebra II	8,379 (23%)
Geometry or lower	2,868 (8.0%)
Unknown	1,569
GPA	3.12 (mean)
Began Math Sequence Pre-AB705 No	10,672 (29%)
Yes	26,560 (71%)
Years between last HS Math and First CCC Math Course	1.00 (mean)
Race/Ethnicity	
African American	919 (2.5%)
Asian	8,272 (22%)
Hispanic	16,055 (43%)
Native American	79 (0.2%)
Pacific Islander	107 (0.3%)
Two or more races	1,859 (5.0%)
Unknown	586 (1.6%)
White	9,355 (25%)
Gender	
Female	13,018 (35%)
Male	24,104 (65%)
Unknown	110 (0.3%)
Age	21.0 (mean)
EOPS	4,113 (11%)
% Underrepresented Students at Students' High School	55 (mean)
% Underrepresented Students at Students' CCC	52 (mean)

Not all variables were entered in the first model but rather a series of six nested models were tested to compare Akaike information criterion (AIC) scores to determine the balance between parsimony and explanatory value. Table 7 below shows coefficients for each predictor variable among each progressively more complex model. The final model includes an interaction between highest high school math completed and the first CCC math variable.

Since each model is predicting successful STEM Calculus 1 completion within two years, positive coefficients indicate a positive relationship with calculus completion, while negative coefficients indicate a negative relationship and are associated with lower likelihood of calculus completion. Coefficients with a plus (+) or asterisks (*) indicate the level of significance (see note below the table for specific p-values).

Note that categorical variables have a "reference" category. For example, for first CCC math, the three types of preparatory courses are in reference to beginning directly in STEM Calculus 1. Note that all three preparatory college courses have negative coefficients across all models meaning that students beginning in a preparatory college course have lower likelihoods of completing STEM Calculus 1 compared to students who directly enroll in STEM Calculus 1 while controlling for differences in other variables such as high school GPA. In turn, high school GPA has positive coefficients meaning that students with higher high school GPAs have higher likelihoods of successfully completing STEM Calculus 1 irrespective of their math starting level.

When comparing models, Model 6 has the lowest AIC suggesting that this model has the most explanatory power. The Bayesian Information Criterion (BIC) had its lowest value with Model 4 as that metric contains a penalty for including more variables. However, given the importance of understanding the interaction effects between first CCC course and highest HS math course completed, Model 6 was selected. The direction of the relationship among variables is consistent across models suggesting stability of the relationships of the predictors and the outcome variable.

Table 7. Logistic Regression Models

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
(Intercept)	−1.869*** (0.093)	−1.994*** (0.097)	−3.687*** (0.195)	−3.651*** (0.196)	−3.126*** (0.205)	−2.987*** (0.207)
First CCC Math Precalculus	−1.276*** (0.032)	−1.293*** (0.032)	−1.261*** (0.033)	−1.267*** (0.033)	−1.242*** (0.034)	−1.517*** (0.066)
First CCC Math Trigonometry	−1.726*** (0.035)	−1.745*** (0.035)	−1.691*** (0.036)	−1.698*** (0.036)	−1.671*** (0.036)	−1.804*** (0.076)
First CCC Math College Algebra	−2.304*** (0.045)	−2.297*** (0.045)	−2.210*** (0.046)	−2.217*** (0.046)	−2.179*** (0.046)	−2.561*** (0.112)
Highest HS Math Trig/Precalculus	−0.447*** (0.033)	−0.427*** (0.033)	−0.421*** (0.034)	−0.432*** (0.034)	−0.488*** (0.034)	−0.737*** (0.054)
Highest HS Math Statistics	−0.521*** (0.050)	−0.485*** (0.051)	−0.509*** (0.051)	−0.518*** (0.051)	−0.620*** (0.052)	−0.833*** (0.125)
Highest HS Math Algebra 2	−0.675*** (0.038)	−0.623*** (0.039)	−0.613*** (0.040)	−0.641*** (0.040)	−0.742*** (0.041)	−0.820*** (0.086)
Highest HS Math Geometry or lower	−0.836*** (0.058)	−0.760*** (0.059)	−0.739*** (0.060)	−0.779*** (0.060)	−0.874*** (0.061)	−0.850*** (0.155)
HS GPA	1.071*** (0.027)	1.066*** (0.027)	1.117*** (0.029)	1.110*** (0.029)	1.111*** (0.029)	1.112*** (0.029)
Began Math Sequence Pre-AB705		0.243*** (0.028)	0.140*** (0.030)	0.145*** (0.030)	0.115*** (0.031)	0.116*** (0.031)
Years between last HS math and first CCC math		−0.033*** (0.009)	−0.062*** (0.010)	−0.052*** (0.010)	−0.040*** (0.010)	−0.039*** (0.010)
Ethnicity - Asian			0.767*** (0.086)	0.772*** (0.087)	0.636*** (0.088)	0.629*** (0.088)
Ethnicity - Hispanic/Latino			0.076 (0.084)	0.071 (0.085)	0.163+ (0.086)	0.156+ (0.086)
Ethnicity - Native American			−0.147 (0.307)	−0.141 (0.309)	−0.254 (0.310)	−0.251 (0.311)
Ethnicity - Pacific Islander			−0.313 (0.259)	−0.293 (0.259)	−0.297 (0.261)	−0.322 (0.262)
Ethnicity - Two or more races			0.433*** (0.099)	0.471*** (0.099)	0.320** (0.101)	0.313** (0.101)
Ethnicity - Unknown			0.456*** (0.128)	0.479*** (0.128)	0.374** (0.130)	0.377** (0.130)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Ethnicity - White			0.423*** (0.086)	0.454*** (0.086)	0.251** (0.088)	0.245** (0.088)
Gender - Male			0.339*** (0.027)	0.363*** (0.027)	0.376*** (0.028)	0.376*** (0.028)
Gender - Unknown			0.005 (0.227)	0.043 (0.226)	0.006 (0.229)	0.007 (0.229)
Age			0.049*** (0.007)	0.045*** (0.007)	0.048*** (0.007)	0.048*** (0.007)
EOPS				0.497*** (0.041)	0.585*** (0.041)	0.586*** (0.041)
% Underrepresented Students at Students’ High School					−0.013*** 0.001)	−0.013*** (0.001)
% Underrepresented Students at Students’ CCC					(0.004*** (0.001)	0.004*** (0.001)
First CCC Math Precalculus:Highest HS Math Trig/Precalculus						0.385*** (0.082)
First CCC Math Trigonometry:Highest HS Math Trig/Precalculus						0.342*** (0.093)
First CCC Math College Algebra:Highest HS Math Trig/Precalculus						0.694*** (0.134)
First CCC Math Precalculus:Highest HS Math Statistics						0.326* (0.152)
First CCC Math Trigonometry:Highest HS Math Statistics						0.238 (0.158)
First CCC Math College Algebra:Highest HS Math Statistics						0.551** (0.195)
First CCC Math Precalculus:Highest HS Math Algebra 2						0.300** (0.108)
First CCC Math Trigonometry:Highest HS Math Algebra 2						0.023 (0.115)
First CCC Math College Algebra:Highest HS Math Algebra 2						0.219 (0.152)
First CCC Math Precalculus:Highest HS Math Geometry or lower						0.321+ (0.182)
First CCC Math Trigonometry:Highest HS Math Geometry or lower						−0.261 (0.191)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
First CCC Math College Algebra:Highest HS Math Geometry or lower						0.151 (0.223)
Num.Obs.	35 663	35 663	35 663	35 663	35 204	35 204
AIC	39 055.8	38 974.1	38 280.3	38 131.1	37 167.1	37 118.6
BIC	39 132.2	39 067.4	38 458.5	38 317.7	37 370.4	37 423.4
Log.Lik.	−19 518.914	−19 476.054	−19 119.172	−19 043.528	−18 559.569	−18 523.278
F	928.736	745.772	385.096	369.247	338.598	220.015
RMSE	0.43	0.43	0.42	0.42	0.42	0.42
+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001						
Logistic Regression R Code						

Model 6 was selected as the final model for viewing odds ratios despite being less parsimonious than Model 4 so that the full set of control variables could be examined. Odds ratios shown in Table 8 are a form of "standardized coefficient." This coefficient allows for the direct comparison of the predictive strengths of variables with different units of measurement, such as starting in a preparatory course and high school GPA. Odds ratios show the change in the odds of successfully completing STEM Calculus 1 within two years for each one-unit change in the predictor variable. Odds ratios greater than one indicate a positive relationship with completion and ratios less than one indicate negative relationship. The further away the ratio is from one, the stronger the relationship. For example, High School GPA, with an odds ratio of 3.04 (see Table 8), has a strong, positive relationship to STEM Calculus 1 completion; for each additional GPA unit (i.e., from 2.0 to 3.0) the odds of completing STEM Calculus 1 within two years increases by 3.04 times.

The key variables of interest are the odds ratios of preparatory courses for STEM Calculus 1. As seen in Table 8, the odds ratios for preparatory courses for the final model were all less than one, which indicates that the probability of completing STEM Calculus 1 is lower for students starting in preparatory courses as compared to students who directly enrolled in STEM Calculus 1. This result is consistent with the descriptive tables presented in the report but notable as these odds ratios hold constant for all other included variables such as high school GPA, level of high school math achieved, student demographics, and the percentages of minoritized students at the student's high school of origin and at the college where the student attempted STEM math.

High school GPA had the largest positive association with throughput (odds ratio furthest from one) and enrollment in College Algebra had the strongest negative association with throughput (odds ratio closest to zero). Indeed, all the preparatory college courses had stronger odds ratios than high school GPA, the next most predictive variable. For example, the odds ratio of 0.08 for College Algebra can be interpreted as follows: holding all else constant, the odds of successful completion of STEM Calculus 1 in two years for students starting in College Algebra are 12.5 times (1/0.08) lower than students starting in STEM Calculus. Taken together, this result means that enrolling in a preparatory course in college is a strong negative predictor of STEM Calculus 1 completion even when controlling for other strong predictors such as high school GPA.

Table 8. Odds Ratios (OR) for Model 6

Variable	OR	95% CI	p-value
First CCC Math			
STEM Calculus I (reference category)			
Precalculus	0.22	0.19, 0.25	<0.001
Trigonometry	0.16	0.14, 0.19	<0.001
College Algebra	0.08	0.06, 0.10	<0.001
Highest HS Math			
Calculus (reference category)			
Precalculus/Trigonometry	0.48	0.43, 0.53	<0.001
Statistics	0.43	0.34, 0.56	<0.001
Algebra II	0.44	0.37, 0.52	<0.001
Geometry or lower	0.43	0.32,0.58	<0.001
Began Math Sequence Pre-AB705			
0 (No, reference category)			

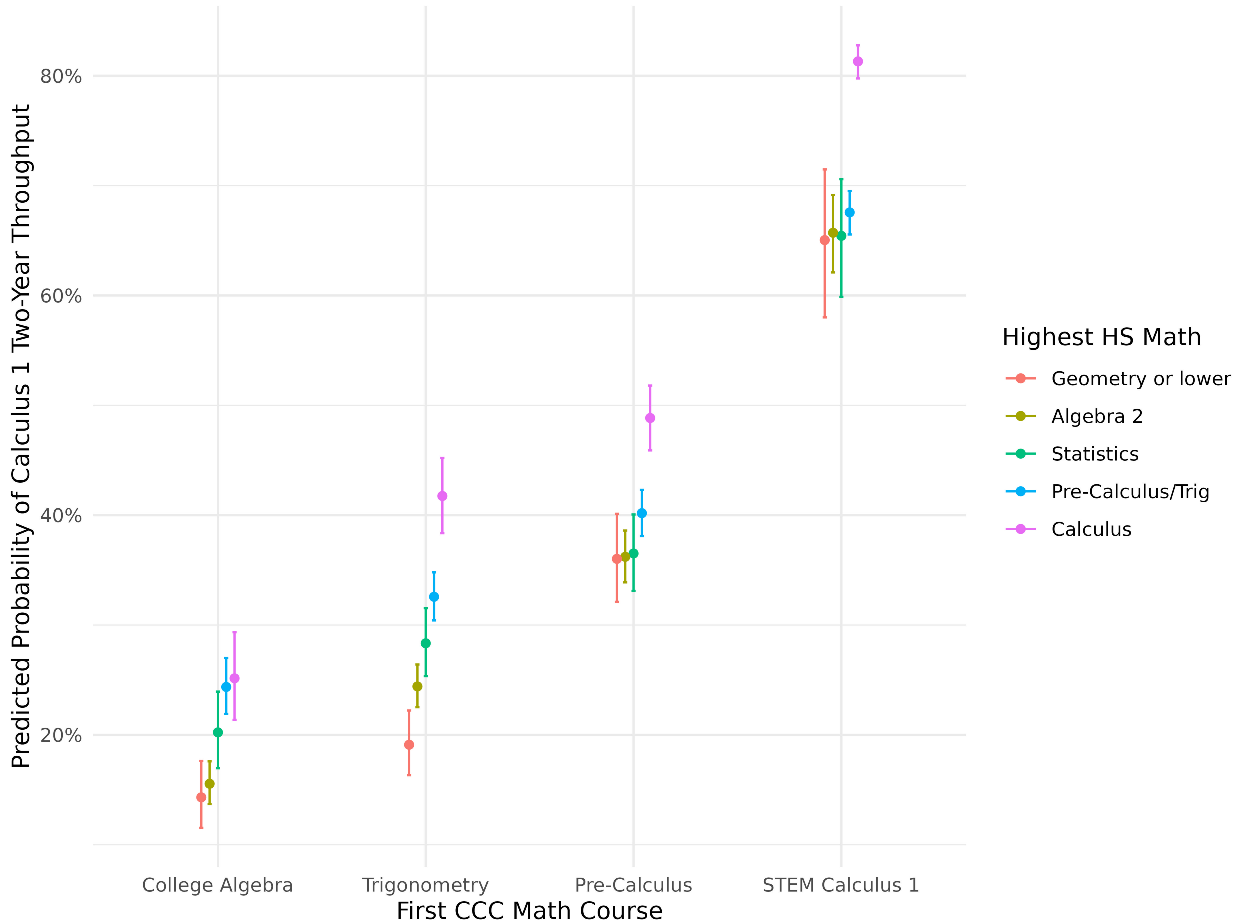
Variable	OR	95% CI	p-value
1 (Yes)	1.12	1.06, 1.19	<0.001
High School GPA	3.04	2.78, 3.22	<0.001
Years between last HS math and first CCC math	0.96	0.94, 0.98	<0.001
Ethnicity			
African American (reference category)			
Asian	1.88	1.58, 2.23	<0.001
Hispanic	1.17	0.99, 1.39	<0.001
Native American	0.78	0.41, 1.41	0.4
Pacific Islander	0.72	0.43, 1.20	0.2
Two or more races	1.37	1.12, 1.67	0.002
Unknown	1.46	1.13, 1.88	0.004
White	1.28	1.08, 1.52	0.006
Gender			
Female (reference category)			
Male	1.46	1.38, 1.54	<0.001
Unknown	1.01	0.64, 1.57	>0.9
Age	1.05	1.03, 1.06	>0.001
EOPS	1.80	1.66, 1.95	<0.001
% Underrepresented Students at Students' High School	0.99	0.99, 0.99	<0.001
% Underrepresented Students at Students' CCC	1.00	1.00, 1.01	<0.001
First CCC Math Rank * Highest HS Math Rank			
Pre-Calculus * Precalculus/Trig	1.47	1.25, 1.72	<0.001
Trigonometry * Precalculus/Trig	1.41	1.17, 1.69	<0.001
College Algebra * Precalculus/Trig	2.00	1.54, 2.61	<0.001
Precalculus * Statistics	1.38	1.03, 1.86	0.033
Trigonometry * Statistics	1.27	0.93, 1.72	0.13
College Algebra * Statistics	1.74	1.18, 2.54	0.005
Precalculus * Algebra II	1.35	1.09, 1.67	0.005
Trigonometry * Algebra II	1.02	0.82, 1.28	0.8
College Algebra * Algebra II	1.24	0.93, 1.68	0.15
Precalculus * Geometry or lower	1.38	0.96, 1.97	0.078
Trigonometry * Geometry or lower	0.77	0.53, 1.12	0.2
College Algebra * Geometry or lower	1.16	0.75, 1.80	0.5

Of particular interest is the relationship between highest high school math successfully completed (grade of C or better) and throughput to Calculus 1 from various college math starting points. Across all demographic groups and holding all other variables constant, starting directly in Calculus 1 is associated with higher throughput than starting in a preparatory college course, across all levels of high school math preparation.

Figure 1 below provides a visual representation of the predicted probability of STEM Calculus 1 throughput within two years for a typical student based on the most comprehensive model (Model 6). In Figure 1, a typical student is operationalized as the modal demographic value, which is in this case is Hispanic/Latino males. Adjusting for the number of years between high school and college math,

student age, HSGPA, and the share of underrepresented students in high school or a community college, a typical student starting directly in Calculus 1 has a higher predicted probability of two-year throughput compared to starting in a preparatory college course for all high school preparation levels. Higher levels of high school math preparation correspond to higher predicted calculus throughput for every course in the STEM calculus pathway; however, across the levels of high school math preparation, a typical student starting in STEM Calculus 1 has a higher predicted calculus throughput than a typical student who completed calculus in high school who starts in a preparatory college course.

Figure 1. Predicted Probability of Two-Year Calculus 1 by Highest Math in High School and Level of First College Math

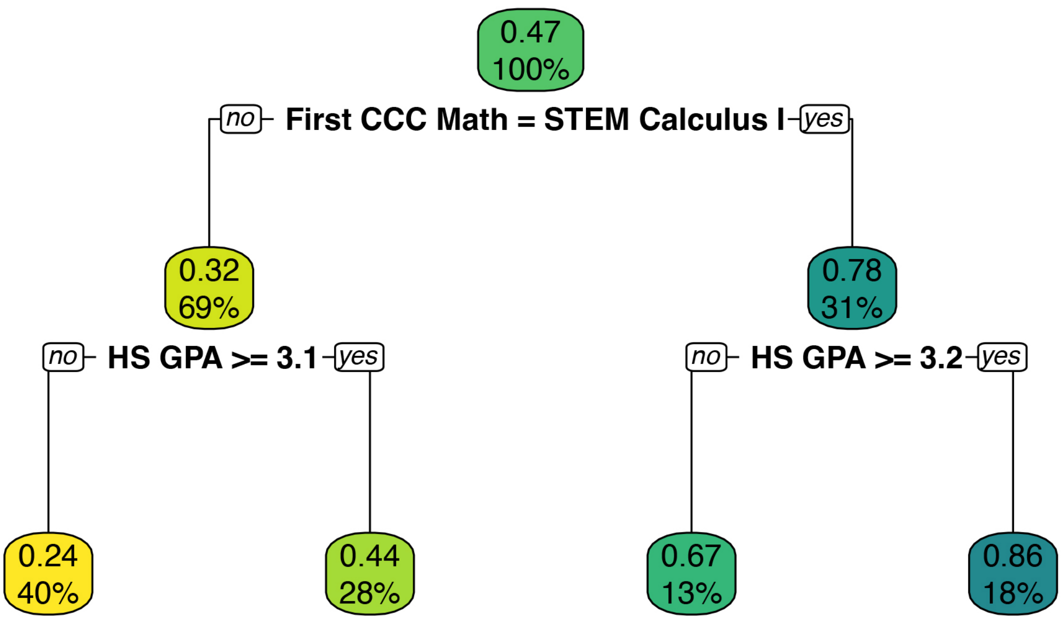


Confirmatory Tree Model

A confirmatory classification and regression tree (CART) model provided a test of whether the findings of the logistic regression were subject to model bias, that is dependent on the predictive model selected as opposed to the patterns of the underlying data. As CART intrinsically includes interaction effects, Model 5 was used instead of Model 6. The only difference between Model 5 and Model 6 in the logistic regression analysis is that Model 5 only includes main effects whereas Model 6 also includes the interaction effects between first CCC math and highest HS math completed.

The tree model reinforces the findings from the logistic regression model with the most predictive variables being starting place in the STEM sequence (first math rank) and high school GPA (Figure 2). Both models showed that direct placement into Calculus 1 is associated with the highest throughput rates. In addition, higher high school GPAs are associated with higher throughputs overall and among students directly placed into Calculus 1. For students with higher high school GPAs (>=3.1) starting in calculus preparatory courses (Precalculus and Trigonometry) was associated with much higher throughput rates than starting in College Algebra presumably due to students only having one course to complete before starting Calculus 1. Students with lower high school GPAs who began in calculus preparatory courses had the lowest throughput rates, about one third of the rate of students with similar GPAs who began directly in Calculus 1.

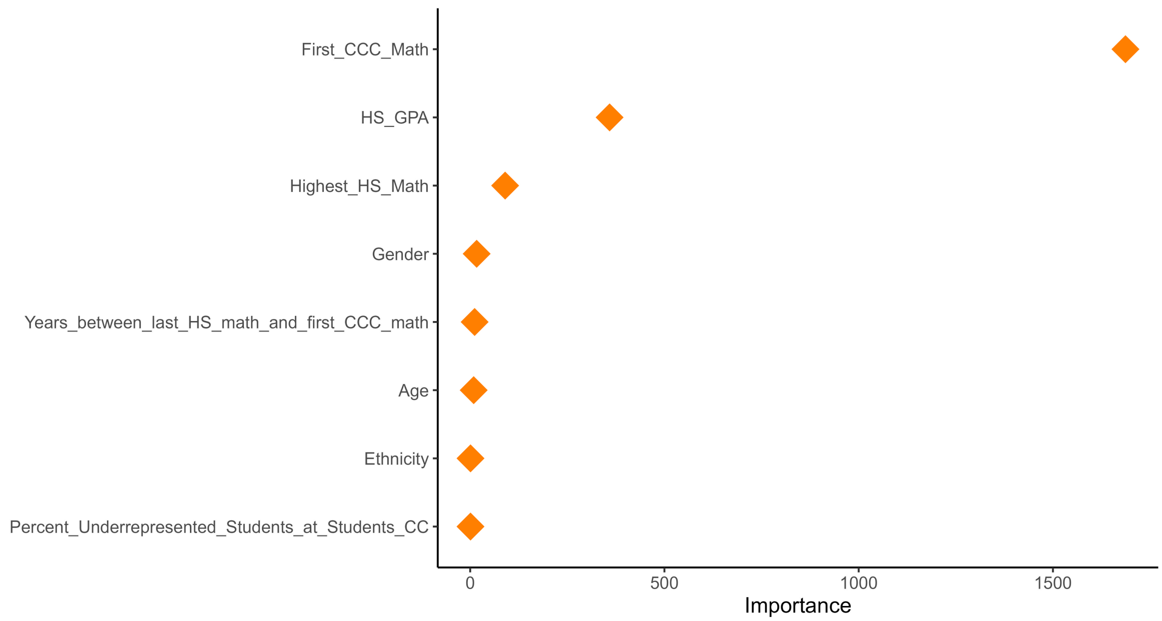
Figure 2. Regression Tree Using Model 5 to Predict Calculus 1 Throughput in Two Years



Notes: The upper value in each node is the proportion of students completing Calculus 1 within two years, while the lower value is the percentage of students in that node. Cross validated error = 0.77 (R square = 0.23). The shading moves from yellow to blue as predicted success rates increase.
Decision Tree R Code

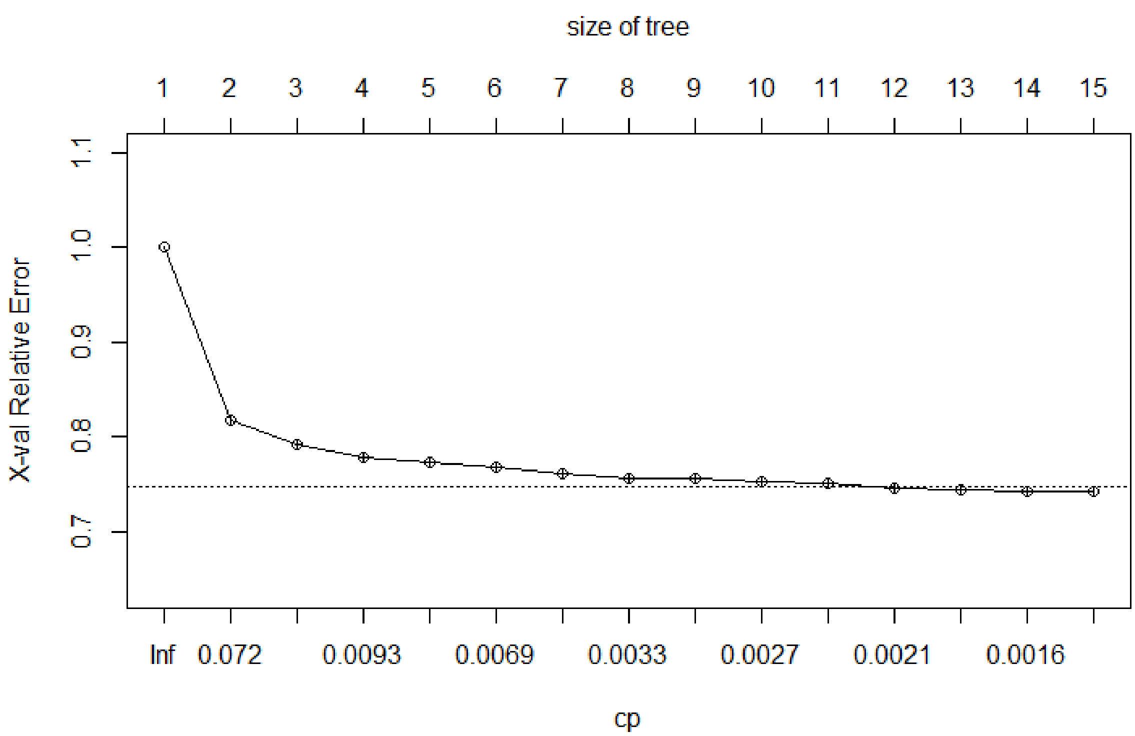
Variable Importance Factors (VIF) were calculated for the decision tree and are conceptually similar to regression coefficients with larger values indicating stronger predictors (Figure 3). The two most important predictors were starting level in STEM math and high school GPA. The next most important factor was the highest level of math completed in high school. However, that and subsequent variables did not make meaningful contributions to the predictive model and were omitted from the final decision tree.

Figure 3. Variable Importance Plot for Predicting Calculus 1 Throughput in Two Years



During the model building phase, an overfit tree was created to determine the optimal number of splits that would provide useful output with a parsimonious model. Examining the scree plot (Figure 4) suggested that more than three splits would not explain sufficient additional variance to warrant making the model more complex, which supports the use of the trimmed tree presented above in Figure 3.

Figure 4. Relative Error Plot of Overfit Tree to Determine Optimal Number of Splits



Findings from the Multivariate Analyses

There was no evidence that preparatory courses for STEM Calculus 1 were associated with improved throughput relative to direct enrollment in calculus. This finding held true even when controlling for high school GPA, level of high school math achieved, student demographics, the percentages of minoritized students at the student's high school of origin and at the college where student attempted STEM math. Prior assumptions that a student's probability of completing STEM Calculus 1 is improved by the requirement of additional preparatory coursework prior to STEM Calculus 1 are not supported by this analysis.

Discussion

The findings are consistent with the prior MMAP research on remedial courses in the context of AB 705 implementation (RP Group, 2017; Bahr, et al., 2019) and on courses preparatory to Business Calculus (RP Group, 2023). That is, additional courses that precede the target course are associated with attrition in excess of any possible benefits of additional preparation. Omitting the effect of attrition resulted in at best only modest gains in success rates for the target course consistent with other research findings (Sonnert & Sadler, 2014). This pattern argues against the premise that students are best served by additional preparation in college prior to calculus. With direct enrollment into STEM Calculus 1, it is possible that other types of concurrent supports such as corequisites, tutoring, and culturally responsive pedagogy, as well as increased diversity of both STEM faculty, may yield more promising results as a strategy for improving STEM Calculus 1 throughput.

Limitations

Students in this data set are not a random sample of all possible students in STEM Calculus and are subject to self-selection both in choosing to go to community college and to be a STEM major. Further, the analyses were limited to students who had CCCApply self-reported information or identifiable California high school math records. Despite extensive error checking and manual recoding of high school and college courses when appropriate, variations in coding accuracy and coding consistency over time and among institutions may be present, e.g., an Analytic Geometry course coded as Geometry instead of Precalculus. One subset where these data limitations may be apparent are students whose high school math preparation was Geometry or lower. While this group is small, it is of interest as these students presumably would have the greatest need for remedial support and/or preparatory courses, their performance in STEM Calculus 1 was greater than perhaps expected. It is possible that some of these students had engaged in additional math preparation outside of high school courses. Other influencing factors such as institutional STEM cultures, classroom conditions, and faculty teaching and grading practices are not captured in these models.

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